BEAM INSTRUMENTATION IN THE LEP PRE-INJECTOR

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Introduction

The main purpose of this paper is to review the beam instrumentation of the LEP pre-injector (LPI) [1] including its design philosophy and software. The usefulness of these equipments for the LPI start-up is considered from an operational point of view and encountered problems are mentioned.

Reminder and history

The LPI consists of three distinct machines [2] :
- a 200 MeV / 2.5 A e- Linac (LIL V) designed for e+ production on a converter target.
- a 600 MeV Linac (LIL W) able to accelerate either 12 mA e+ coming from LILV or 70 mA e- produced by a dedicated low-current e- gun
- an Electron-Positron Accumulator (EPA) in which an intense beam of e+ or e- is built up prior to its transfer to the Protron Synchrotron (PS).

The two Linacs produce pulses of 10 to 24 ns at a maximum 100 Hz rate that EPA stacks for one or several Basic Periods of 1.2 s depending on beam characteristics required.

Electron commissioning started with LIL W in December 85, with EPA in June 86 and ended in December 86 with a 2 week-run of e- production for PS tests.

Instrumentation (FIG1)

At the beam level, instrumentation was designed :
- to get complete information on parameters at each node
- to monitor all the main adjustments unambiguously and to get, at a glance, a good description of beam behaviour through all phases of its production.

At the realisation level, care was taken
- to use preferably equipment already existing in CERN (SEMgrids , TV screens , electronics)
- to build instrumentation widely usable as a new standard tool (Magnetic pick-up)

Magnetic pick up (UMA) [3]

This new type of monitor, identical for LIL, EPA and the transfer lines, was preferred to electrostatic devices because of its low sensitivity to losses, its compactness, its low longitudinal impedance (0.1 Ω) and its ability to deliver a good Sum (Σ) signal to enable precise appreciation of beam transmission. It produces Σ, ΔH and ΔV signals in the 500kHz to 250 MHz bandwidth . Two amplification factors, and averaging over up to 100 measurements, allow for treatment of bunches of a few 10**8 to a few 10**11 particles with a typical 0.5 mm resolution within a ± 40 mm aperture.

LIL V & LIL W are equiped with 15 units ; 20 are disposed around EPA in places where βH and βV are close to maximum. The high number of UMAs around EPA gives a precise orbit definition which permits orbit corrections by adjustment of quadrupole positions avoiding the necessity of correction dipoles. Finally, 8 are located in the different transfer lines (2 between EPA and PS not shown on the drawing).

All analog signals are available on a patch panel and through a standard computer-controlled multiplexer. From acquired digital data, alphanumeric displays are elaborated - one for LIL V and LIL W trajectories and transmission, one for EPA orbits -. Basically, in EPA, trajectories are measured on one specific turn, for a defined bunch. Averaging over a number of injections provides trajectory measurement as long as the circulating beam is dumped before every new injection. Orbits are determined through averaging of consecutive trajectories with a stored beam. Graphical displays exist for EPA orbits and trajectories.

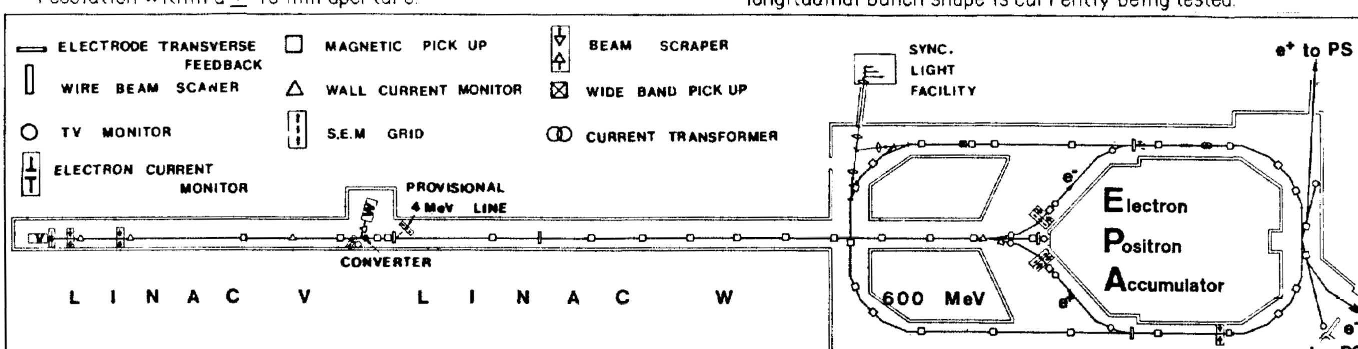
Synchrotron Radiation Monitor (MSR) [4]

The 4 bending magnets of one EPA quadrant are equiped with exit ports for visible synchrotron light : two ports are dedicated to e- and two to e+ radiation but only one of each is fully equiped at the moment; the two remaining ports are being completed to perform energy dispersion measurement. Each port contains an extraction water-cooled copper mirror reflecting the light upwards through a 74 mm diameter sapphire window. Hanging from a precision rail fixed on the ceiling(FIG 2), two 100 mm diameter achromats, metallic and pellicle beamsplitters direct the beams to a single point on an optical bench located in a dedicated lab outside restricted access area. There one or two lenses form an image distributed to 5 measurement points through another set of pellicle beam-splitters. Each optical element located inside the EPA building is carried by an individual and fully adjustable holder. The optical lines are housed in metallic foam coated containers linked by plastic tubes to protect them against shocks, vibrations, dust and ambient light.

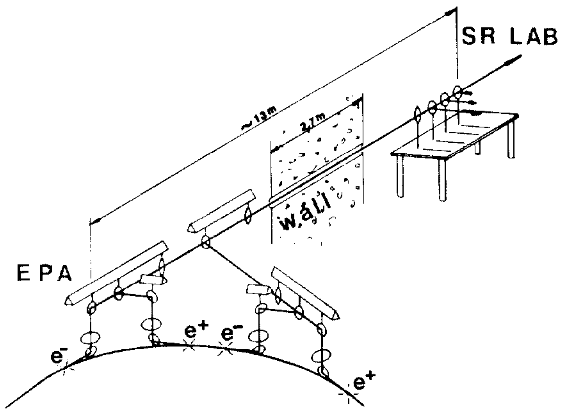
Beam images are produced 13m from their sources with 2 possible magnifications and apertures :
- Magnification M = .26, aperture A = ± 30 mm H, ± 20 mm V
- Magnification M = .8 , aperture A = ± 10 mm in both planes

For the moment, 2 devices are used :
- a simple Vidicon TV camera to permanently monitor the beam envelope,
- a transverse profile camera using 1024 ø 0.5mm optical fibers arranged in 32 rows driving 32 discrete photodiodes to provide the transverse profile of one selected bunch at a maximum 1kHz rate. A HP 9920 microcomputer elaborates, from the raw data, mountain range displays, computes spline and Gaussian fits or determines the transverse damping time.

A silicon avalanche diode to provide analog signals of longitudinal bunch shape is currently being tested.



- FIG 1 -



- FIG 2 -

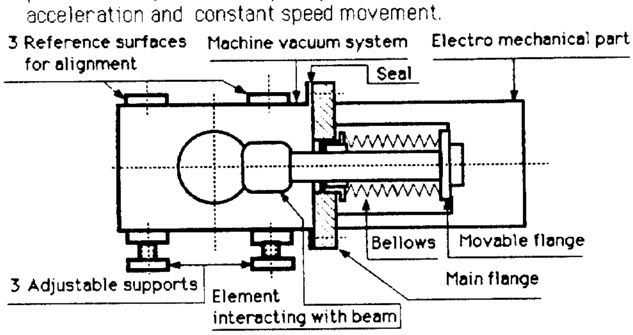
Wide band pick-up (UWB) [5]

This wall-current type device delivers the longitudinal and the transversal profiles in the 9.5 MHz to 1.5 GHz bandwidth.

Associated with a Mountain Range Display facility, and a 7104 Tektronix scope, it constitutes a good tool to observe longitudinal and coherent transversal instabilities.

Moving instrumentation

There are Wire Beam Scanners(WBS), SEMgrids(MSH), adjustable Slits (SLH) and TV monitor sreens (MTV). For all of them, the movement is transmitted into the vacuum through a sealed flange on which is welded, air side, a thin walled bellows closed on its other end and containing all the electro-mechanical equipment.This flange is used as position reference for the mechanism. The whole assembly is mounted on a pre-aligned tank (FIG3). This solution offers minimum vacuum risks and allows for easy standard exchange of instruments. When precise positioning or constant speed is required, stepping motors coupled with a multi-turn absolute shaft-encoder are used. These motors are controlled through a pulse train, the frequency of which determines both acceleration and constant speed movement.



-FIG 3 -

Wire Beam Scanner (WBS): It consists of an arm holding two perpendicular .25mm beryllium wires strung between the two prongs of a fork. This arm moves diagonally back and forth at a maximum 70mm/s speed so that one wire sweeps horizontally across the beam and the other one crosses it vertically. Three grounded 100µm Al or 50µm Cu sheets respectively in front, between the two wires and at the back collect parasitic secondary electrons and stray low energy particles.

Two methods are used to perform beam profile measurements :

- constant speed sweeping with beam pulsing and charge sampling at the maximum 100 Hz rate; depending on beam size 16mm stroke - 15mm/s or 50mm stroke - 45mm/s projected speeds are used
- variable step by step movement controlled by the Linac repetition rate.

Data is collected during a single crossing of the beam with one of 4 ranges from 10**6 to 5 . 10**11 e± / mm

Five WBSs are installed to give profiles or, associated with quadrupole controls, to measure emittances or matching. They give significant measurements on stable repetitive beams.

SEMgrids (MSH) [6] : Originally developed for CERN LEAR and 50MeV Proton Linac they consist of 26 vertical titanium strips of 1.5mm/7µm covering a 42.5 mm wide frame.The resolution can be varied in a 1 to 3 range through control of angle between grid-plane and beam. On both sides of the grid plane 7µm titanium foils are polarized to capture secondary e-. Two gain ranges combined with two integrator settings result in ability to measure beams from 3.10**5 to 2.10**11 particles within 10 ms.

Two MSHs are installed in EPA injection lines and one in the LIL V 200 MeV line for mean energy and spread measurements. Graphical displays are available on every PS standard operation console.

S l i t s (SLH/V) : Each arm of the slit is constituted of a metallic block welded at the end of a hollow water-cooled stem. Two stepping motors control the mean position and the width of the slit respectively through lead screws coupled by two differentials.

Five devices are located in LIL, EPA injection lines and ring to reduce intensity and/or select a part of energy spectrum.

T V monitors (MTV) : A linear drive rotates an arm which carries a 1mm thick ceramic screen engraved with a 10mm pitch grid. Beam hits the screen at a 45º incidence and a TV camera perpendicular to the beam delivers a video signal available through a standard multiplexing facility on operation consoles.

Thirteen of those are distributed in LIL and EPA to monitor beam stability and energy (4 in the tranfer lines to the PS are not shown on the general lay-out).

Electrode Transverse Feedback (ETF)

Housed in a ø100mm , 850 mm long standard EPA vacuum pipe, the ETF consists of four 800mm long and 26 mm wide prestressed and copper plated stainless steel blades. Two are in the horizontal plane and two in the vertical. Each one is connected to a HT-feedthrough.

Besides feedback purposes, the electrode is used to excite the beam circulating in EPA for Q-measurement.

Wall Current Monitor (WCM) [7]

Twenty 125Ω resistors bridging a gap surrounded by 3 ferrite rings delivers a voltage proportionnal to the beam current within a bandwidth of 150 kHz to 2 GHz with a sensitivity of 4.4 V / A.

Five WCMs are in use in LIL V and LIL W to deliver longitudinal beam profiles. Analog signals are observed on Tek 7104 scope and digital displays are also available

Electron Current Monitor (ECM) [8]

This 40 mm diameter and 32 mm long cylindrical electrostatic monitor provides a beam intensity measurement within a 1 to 500 MHz bandwidth.

The only existing unit is used to measure LIL V gun current with a 30 mV/ A sensitivity.

O p e r a t i o n a l a s p e c t s

In every new machine or process three different functioning phases have to be described : [A] search for first beam, [B] performance consolidation, [C] routine operation. During these periods instrumentation should be successively simple and reliable [A], precise and with good performance [B] then, finally, complete and easy to use for quick diagnostics [C].

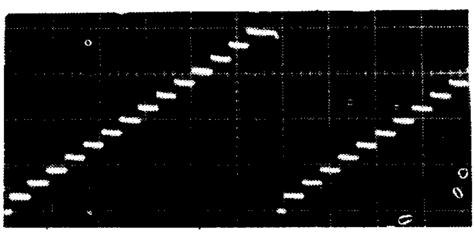
In the case of LPI, three machines and two types of particles are involved.Up to now there has been the following periods :

1) December 85 - May 86 : first LILW beams (e-)
2) June 86 : LIL W consolidation and first beam in EPA
3) July 86 - November 86 : LIL W operation and EPA e- consolidation
4) December 86 : LPI e- operation

1) During an introductory 4 MeV run in December and January [9], a provisional spectrometer involving a SEMgrid was installed. Other instrumentation consisted of 2 WCMs, 2 UMAs and 1 WBS : UMA analog signals showed beam ≥300 μA and WBS in continuous sweeping mode gave good profiles on the forward crossing but noisy ones on the return due to mechanical friction; MSH, missing its polarization sheets, was not properly usable until good focusing was obtained because of local losses and despite attempts of polarization on the grid itself. WBS and MSH controls and displays were realized through one Macintosh computer as a stand-alone CAMAC control system [10]. The lack of a TV monitor was strongly felt.

After 2 months of installation for EPA, LIL tests resumed in March concluding in May with a 260 MeV beam in EPA e- injection line: according to progress, the UMA acquisition timing was set-up. Reliable alphanumerical transmission and trajectories were available when a 100Hz beam was produced by LIL W. The 3 WBSs involved worked first in a step by step mode to get rid of the increasing mechanical noise then again in continuous sweep and controlled from the standard operation console once the vibration had been removed; TV monitors were very useful to monitor the beam when adjusting klystron HF phases and the SEMgrid in e- injection line was used from mid-May to evaluate the energy spread.

2) During this second period beam was injected into EPA at energies ranging from 400 to 510 MeV : injection was adjusted with TV monitors and UMA analog signals then an alphanumerical EPA data on orbits were available. Q measurements were performed with a HP71100 spectrum analyser first on injection oscillations then by exciting a stored beam through the ETF. They were in good agreement with the actual settings of the 6 families of quadrupoles within .005 for QH and .04 for QV. Lacking a current transformer (to come in June 87), EPA beam intensity was obtained by sampling the base line of the Σ signal of one UMA which despite the bunch shape and timing dependences was precise to a few % (FIG3).



H = 200 ms

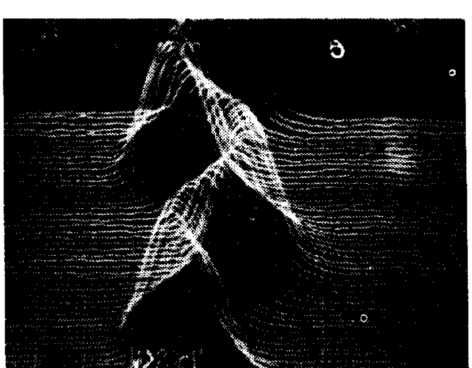
V = 100 mV

per division

- FIG 3 -

All the moving instrumentation performed well, some devices having already performed about 10000 movements. MSR was a very powerful monitoring device from the very first day of injection into EPA : it was used with the 0.2 magnification and a sensitive TV camera with light amplifier.

3) From July, stacking and ejection of high intensity beams in 1 to 8 bunches at 500 MeV was achieved. Beam to the PS was provided in several sessions; the spectrum analyser was used intensively to analyse transverse and longitudinal instabilities, measure tunes, chromaticities and growth rates. The bunch length versus current was measured with UWB, which was also used with the mountain range display to show longitudinal instabilities (FIG4).

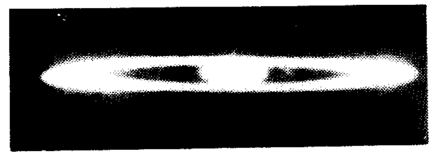


Bunch synchrotronic oscillation (fs=3.84 kHz)
8 bunches
N= 3. 10**11
E = 500 MeV

- FIG 4 -

MSR used with .8 magnification and a normal TV camera was very helpful to observe exotic beams (FIG5); the transverse camera became available with its associated software; transverse damping times were evaluated from these profiles. Two problems arose with the MSR :

- the first one, due to X-rays, was the degradation of the plating on the extraction mirror (Al+MgF2), leading to a 8 fold sensitivity reduction in a way that was found exactly similar to the NSLS devices [11]. Replacement parts are being prepared with an electroless Nickel coating covered by a thin gold flash,
- the second one was the 20 mrem radiation level in the SR lab in a small zone, along the axis at the end of the optical line.



Beam close to third order resonnance

- FIG 5 -

4) At last, during the December run with the PS, monitoring was performed using alphanumeric displays of UMAs in LIL W as well as MSR TV signal. Trajectories could be acquired at that time at any LIL W beam production rate.

During LIL V 200MeV tests, at high current, the WBS located right in front of the converter does not apparently suffer from back-scattering.

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Many people from the CERN PS Division and from LAL performed hard work to get all these instruments ready in time, which was most valuable for the LPI commissioning. In particular, authors want to thank Mr. Marcarini in charge of hardware aspects and Mr. Heinze for interfacing with Mcintosh.

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